

## Pathfinder Operations

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*In 1981, the Inter-Agency Consultative Group (composed of European, Soviet, Japanese and American space agency representatives) conceived the idea of using the two Soviet Vega spacecraft as pathfinders for Giotto since they would arrive at Halley's Comet approximately one week before Giotto. The Vega trajectory data and the Halley camera angle data were combined to improve the comet orbit accuracy. This was used to improve the Giotto fly-by targeting. The DSN performed delta DOR (VLBI) and one-way Doppler measurements of the Vega spacecraft for orbit determination. Although the early start-up phase had many problems, the results during the critical November 30, 1985 to March 4, 1986 operational phase had an overall 95 percent success rate, with 59 successes out of 62 two-station passes.*

### I. Introduction

When the Giotto flyby of the nucleus of Halley's Comet was being planned several years ago, it was realized that a mismatch existed between the requirement to fly close to the nucleus and the knowledge of exactly where the nucleus would be located. In 1981, the Inter-Agency Consultative Group (composed of European, Soviet, Japanese and American space agency representatives) conceived the idea of using the two Soviet Vega spacecraft as pathfinders for Giotto since they were to continue on a trajectory to Halley's Comet after flying by Venus and arriving approximately one week before Giotto.

The concept was to tie the orbit of the comet accurately to an Earth-referenced frame. The trajectory of the Giotto spacecraft, which would also be accurately known from

Earth-based tracking, could be adjusted to pass by the comet at the desired location.

The position of the Vega spacecraft with respect to Halley's Comet could be determined by optical navigation, using on-board imaging systems. The position of the Vega spacecraft with respect to the Earth could be determined with very accurate tracking. The orbits of the Vega spacecraft could be determined using three types of tracking data: Doppler, ranging, and Delta Differential One-way Range (delta DOR), which is based on interferometric techniques and yields the apparent angle from the spacecraft to a reference celestial source (quasars are used) as seen from Earth.

The Soviet's would acquire the first two types of data using their tracking network. It would be the role of DSN network to obtain the delta DOR data. The most critical

period for data acquisition would be that period leading up to the flyby of the comet by the Vega spacecraft. Because of the limited number of delta DOR passes that could be scheduled, seven in February and three in early March, it would be necessary for the DSN to perform flawlessly.

## II. DSS Configuration

The configuration of the DSN 64-m subnet for the Pathfinder Mission was essentially the same as that used for the Venus-Balloon Mission (Ref. 1). The only significant change was the utilization of the DSS Spectrum Processing Subsystem (DSP) in the Very Long Baseline Interferometry (VLBI) mode, which was not utilized for the Venus-Balloon Mission, as the DSP was needed for recovering Telemetry. The configuration is shown in Fig. 1. The received signal was at 1668 MHz (L-band), the same frequency as Venus-Balloon. In order to maximize the reliability of VLBI data return for the Pathfinder Mission, the DSN used redundancy wherever possible. The primary data path was through the VLBI-Radio Science Receiver (MMR) and DSN Spectrum Processing Subsystem. However, to provide a redundant path, the Block IV receiver was configured in an open-loop mode feeding the Block 0 VLBI Subsystem and the Occultation Data Assembly. This provided an alternate path for the data in case of an MMR or DSP failure.

The primary path was the preferred and most used of the paths. The DSP could be configured and controlled through configuration messages routed from the Network Operations and Control Center (NOCC) at JPL via the DSS Monitor and Control Subsystem, thus reducing the DSS operator load. The backup paths required extensive operator intervention to configure and control and were not considered desirable for primary operations.

## III. Mission Operations

Because of the special nature of this mission it was necessary to provide a separate mission operation team and unique procedures to ensure the success of this mission. The role of the special team was to provide the real time and non-real time support to the normal multi-mission operations teams. This effort included the generation of Pathfinder unique Sequence of Events (SOEs), the generation of special antenna pointing predicts, and the real time monitoring of the spacecraft tracking and the data reduction.

### A. Sequence of Events

Because the two Vega spacecraft were under the control of the Soviets and had to be commanded into the 1.67-GHz

delta DOR transmit mode, for each pass it was necessary to construct a very accurate sequence of events. The spacecraft was in a delta DOR transmit mode for only thirty minutes every two hours. Therefore it was necessary to coordinate the spacecraft turn on times such that both spacecraft would be in the delta DOR mode during the short periods of mutual visibility between DSS 63 and DSS 14 and again between DSS 14 and DSS 43.

A typical sequence follows, in Universal Time, Coordinated (UTC):

- 00:00 Vega 2 commanded on by Soviets
- 03:45 Vega 1 commanded on by Soviets
- 09:10 DSS 63 acquires Vega 2, extracts one-way Doppler, verifies spacecraft modes
- 09:45 DSS 63 acquires Vega 1, extracts one-way Doppler, verifies spacecraft modes
- 10:30 DSS 63 reacquires Vega 2
- 11:04 DSS 14/63 Antenna slews to Quasar 3C 273
- 11:10 DSS 14/63 Start DSP recordings
- 11:18 DSS 14/63 Stop DSP recordings, Antennas slew to Vega 1
- 11:23 DSS 14/63 Start DSP recordings
- 11:30 DSS 14/63 Stop DSP recordings, Antennas slew to Vega 2
- 11:35 DSS 14/63 Start DSP recordings
- 11:42 DSS 14/63 Stop DSP recordings, Antennas slew to Quasar DW 1335-12
- 11:47 DSS 14/63 Start DSP recordings
- 11:55 DSS 14/63 Stop DSP recordings, DSS 14 slews to Vega 1, DSS 63 End of Track

DSS 14 continues to track one of the two Vega spacecraft until DSS 43 rises, at which time the delta DOR sequence is repeated.

### B. Predicts

Normally, for delta DOR observations, the spacecraft is tracked using spacecraft predicts and the quasar is tracked using sidereal tracking. The quasar celestial position is used. For the Pathfinder mission, a single program was used to generate the pointing predicts for both the spacecraft and the quasar. This program was a modification of an existing program normally used for radio source tracking. Using a single

program for all pointing eliminated the need for antenna mode switching when changing from spacecraft to quasar.

In addition, these predicts incorporate a basic model of the 1.6 GHz (L-band) pointing offsets required at each 64-m antenna in order to achieve boresight. The offsets are necessary because of physical constraints in mounting the L-band feed. Because of its large physical size, the L-band feedhorn could not be mounted so that its optical axis would lie on the cone described by rotating the Subreflector. Rather, it is mounted between, and slightly outboard of two of the 64-m Tricones. In order to steer the L-band beam to the proper point in the antenna's local celestial sphere, pointing offsets must be applied to the antenna predicts. The required pointing offsets were determined at each 64-m antenna and the offsets incorporated in the antenna pointing predicts program.

### C. Data Processing

Delta DOR data obtained by the participating DSS' were replayed from the DSS' to a central processing facility located in the NOCC. Data from the spacecraft(s) are separated from the data recorded while tracking the quasar, and processed independently (Fig. 2). Both data sets are subjected to the same processing functions: correlation to extract signal phase, data compression to build signal-to-noise ratio, and computation of delay.

1. **QUASAR.** A model of the interferometric phase is developed from the acquisition frequency configuration and values for station location, quasar position, and media delays. A search is made for clock offset between stations and the quasar data are cross-correlated. One second averages of model phase, and sine and cosine correlation coefficients representing residual phase, are computed by the program VCOROP. The program PHASOR then divides the data into sections of about 30 seconds, and outputs model and residual phase for the midpoint of each section.

2. **SPACECRAFT.** A nominal spacecraft trajectory file is used to generate polynomial models for the expected received spacecraft phase at each station. The function Signal Extrac-

tion by Tone Tracking (SEXTNT) uses this information and the program PHASETRK to search in frequency for the offset between the predicted and actual spacecraft signal. A new model polynomial is derived from the data and this data is further processed using the program POSTRK. The output of this process is the spacecraft model phase and the residual phase.

3. **BWS.** The observed delay for both the spacecraft and the quasar is calculated in the BWS program. These delays, along with appropriate time tags, are output to interface with the Orbit Determination Program (ODP).

## IV. Performance

The performance of October and November was not of the quality necessary to support Pathfinder. High data loss during this period was attributed to equipment failures, which is not surprising, since much of the equipment had only recently been installed. This was indicative of the DSP at DSS 63, which had problems with this subsystem throughout this period. There were a few procedural problems, but these soon disappeared as the operations personnel became familiar with the procedures. Probably the most significant item which led to the final success, was the utilization of a predicts program which drove the antennas in a relatively unattended mode. This alone allowed the operators to monitor the operation of the remaining subsystems in a more effective manner. Also, equally important to the success was the diligent monitoring of the operations by the team in the NOCC. They were well prepared with operational work-arounds in case of need. This was demonstrated when the subreflector positioner at DSS 43 failed during a pass and a new pointing offset had to be derived and added to the predict set at DSS 43. The final performance of the DSN for Pathfinder is depicted in Fig. 3 for the critical operations period of November 30, 1985 through March 4, 1986, the end of the Pathfinder operations effort. The overall final performance of 95 percent with 59 successes out of 62 scheduled two-station passes (one spacecraft orientation problem, two DSN problems) for the Pathfinder mission is a credit to all involved personnel.

## Reference

1. Stelzried, C. T., et al., "The Venus Balloon Project," *TDA Progress Report 42-85*, pp. 191-195, Jet Propulsion Laboratory, Pasadena, Calif., May 15, 1986.

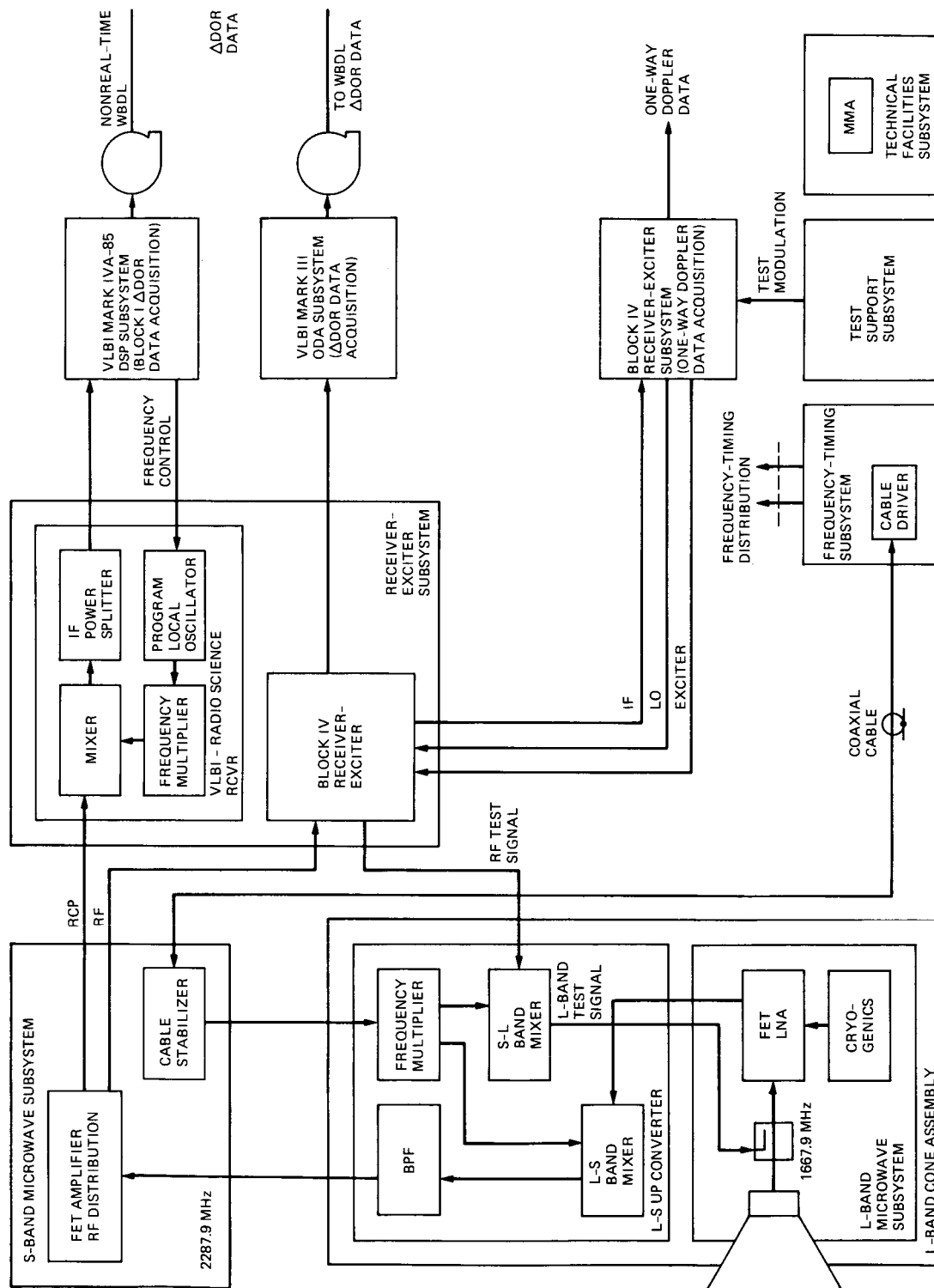


Fig. 1. 1.67-GHz (L-band) configuration block diagram

